ORGANIZATION OF A SYSTEM OF ACTIONS IN THE CASE OF RANDOM ALTERNATION OF SIGNALS

Ye.S. Rogovenko

In the present investigation we consider one of the new experimental methods of studying the higher nervous activity of man on the basis of the characteristics of a finite automaton with two inputs and four states. The data presented below can be considered as the original data for developing a test which will evaluate man as a decision-making mechanism, relating an incoming signal to the result of a prior action. The importance of working out such tests for the development of space science is without doubt. Since man is a link in a spacecraft and situation control system, it is necessary for him to evaluate control possibilities at any required instant. The present investigation is devoted to this problem.

The classical experiments of I. P. Pavlov's school on animals demonstrated that a dynamic stereotype of conditioned reflexes, developed with regular application of conditioning stimuli, always in the same sequence, can remain invariable if the usual order of sequence of the conditioned signals is interrupted [1, 3, 9]. Relying on these facts, Asratyan [2] expressed the idea that a dynamic stereotype reveals the capability of the brain to program its activity. In our previous experiments with dogs [4] we found that after prolonged application of a stereotype consisting of two alternating stimuli (positive and inhibitive), the formation of another stereotype consisting of new signals, positive only, is complicated by /87
the fact that the reflex to the stimulus that occupied the inhibitive positions of the previous stereotype was reinforced with great difficulty. In Rokotova's experiments [5] with dogs and monkeys it was shown that it is possible to form a system of response reactions that avoids the use of concrete stimuli and is sustained by interreflex links. These facts make it possible to suggest that in the process of forming a stereotype interval links are established between conditioned reactions and that these links are more substantial than those between external signals and response reactions to these signals.

In the investigations of our laboratory [6, 7], a human being set up lengthy ordered sequences of actions (pressing keys on a panel) in the presence of a conditioning stimulus. In the learning process the test subjects themselves were to establish the order of actions and to reproduce the order correctly. The test subject set up his own program of actions by forming interval links between individual motor acts, in which case the external stimulus fulfilled the role of a triggering signal.

The working out of the dynamic stereotype in the experiment is a particular and, to a certain degree, an artificial example of organization of stereotype activity. It differs from what is done in daily life by the stability of the conditions under which the man or animal has to structure his activity. Let us assume that the man is subjected to a number of actions and does not know in what order they will be applied. Each action in turn may be related to several different reactions, either the one or the other reaction being the correct one, depending on the conditions. In order to realize the correct reactions, the man must evaluate the

conditions under which he must act. It can be imagined that the organization of a system of actions in such a situation proves to be a complicated process, consisting of several problems: classification of all reactions into groups consistent with each of the actions and the establishment of links between reactions within one group and between reactions pertaining to different groups. And to do so it is necessary to consider whether one and the same action is continuing or whether it is changing. If man meets these requirements he will be able to react correctly to any sequence of external actions an unlimited number of times. Naturally, in such a situation the external signals must not lose their value, even when the human being has already formed his system of actions.

A part of the problem of the present research was to determine how man organizes his activity when, in order to make a decision with respect to a consecutive action, he must evaluate the preceding action and at the same time take the prevailing signal into account. /88

With this aim in mind we carried out experiments in which the following experimental conditions were set up: 1) a random sequence of two equally probable signals (red and green lights) was used; 2) the actions of the test subjects consisted in pressing four keys arranged in a row in the experimental panel; 3) two possible actions were connected with each signal; and 4) transistions from key to key were established by rules which were pre-set by the experimenter. In bold outline the rules consisted in alternating key-pressing operations related to a specific signal if the signal was repeated several times. If the signals varied, it was necessary to move from one group of keys to another, depending on the location of the preceding action.

The object of this investigation was to study methods of organizing a system of actions and of finding the rules necessary to solve the problem.

METHOD

Test Subjects. These were 9 persons of both sexes, ages 17 to 30, volunteers. The majority had previously participated in psychophysiological tests.

Experimental Setup. This consisted of two panels. The test subjects' panel measured 25 x 35 cm containing four keys, of the inverted N type, arranged in a row, 6 cm apart. Above the keys in the center of the panel were two small lights (red and green), covered with frosted glass. On the experimenter's panel were arranged 4 keys of the inverted N type and 4 small lights wired to the keys of the test subjects' panel. With one of the keys the experimenter triggers a signal on the test subjects' panel. The test subject can extinguish it only by pressing the appropriate key on his panel. At the instant the test subject presses a key, the light on the experimenter's panel that is wired to this key flashes. By means of this set up we were able to monitor the entire course of the search for the correct key.

The instructions were issued prior to starting the experiment and read as follows: "When the red, or the green, signal flashes, you must find the key that will turn it off. If you press a key and the signal does not turn off, continue your search. Your problem is to learn to extinguish the lit signal without error."

Experimental Procedure. The test subject was located in the same room with the experimenter and sat back to back with him during the experiment. The time intervals from the instant the signal was extinguished to the time the next was turned on was 1 to 1.5 sec. The problem was presented to the test subject during a single experiment lasting from 1 to 2 hours. If the test subject asked /89
to take a break, the experiment was recessed for 5-10 min.

Program. A random sequence of two signals intended for 1000 tests was programmed in a Ural - 2 computer. The probability of appearance of each signal was 0.5. The program of the experiment was put together in consultation with and with the aid of V.I. Varshavskiy. It was based on certain rules characterizing the operation of finite automata. A diagram of the rules is given in Fig. 1. The circles represent the panel keys. Crossovers from key to key on the red signal are indicated by a solid arrow, while those for the green signal are indicated by broken arrows. By the condition of the experiment each signal may trigger two actions. We specified that on the red signal (R) the test subjects had to press either the first or third keys and on the green signal (G) either the second or fourth keys. In view of the random sequence of the signals, the latter could be applied in the following combinations: RR, GG, RG and GR. The operational rules for any combination are as follows: 1) when the signal G is repeated several times in succession, it is required to change alternately from the 2nd to the 4th and from the 4th to the 2nd keys; 2) when the signal R is repeated several times in succession, it is required to change alternately from the 1st to the 3rd and from the 3rd to the 1st keys; 3) if the signal R is followed by the signal G, it is required to change over to the next key on the right; 4) if the signal G is followed by the signal R, it is required to change over to the next key on the left.

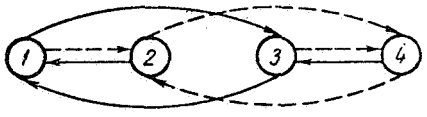

Figure 1. Diagram of the Rules of the Experimental Program. The Circles Represent the Keys of the Panel; the Solid Arrows are Changeovers on the Red Signal; the Broken Arrows are the Same for the Green Signal.

The realization of these rules in the experimental program was incident to establishing a series of moves by the arrows of a graph which would be superimposed on the random series of signals. In the experiment the experimenter reproduced the program by simultaneously turning on the signal (from the random series) and "unlocking" a specific key (according to the diagram of the automaton). The problem of the test subject consisted in identifying the signal and searching for the key which at the given instant would extinguish it. The signal could be turned off by the key that was "opened" by the experimenter and occupied a specific position in the scheme of the automaton.

Indexes. All the correct and erroneous responses of the test subject during /90
the learning period.

Learning Criterion. The problem was considered to be completed when the test subject followed his last error by three correct repetitions of all the programmed moves in accordance with the arrows of the graph.

Experimental Results

Our experiments demonstrated that all the test subjects learned the proposed problem after 276 ± 53 applications of the signals. It was found that after 20-30 signals all the people, regardless of the individual differences in speed of learning, began to observe certain regularities in the erroneous actions. In the majority of cases the errors were noted in the same combinations of signals and were identical in various test subjects.

Under our experimental conditions, each person was to perform two tasks: divide the entire set of his actions (pressing four keys) into two subsets (pressing two pairs of keys), connect each of them with a distinct signal and establish the transitions from one action to the next when the same signal was repeated and when the signals changed. Therefore, in analyzing the incorrect actions, all the errors were divided into two groups. Referred to errors of the first group were those cases when the test subjects completed actions which were related to another signal. A diminution of these errors should have indicated how people distribute their actions relative to the signals. Referred to errors of the second group were those cases when the test subjects executed an action connected with the prevailing signal, but which was not the right one at that instant. A reduction of errors in this group should have indicated how the people established relations between actions and various signal combinations.

In order to be able to compare the data of individual test subjects we made use of the Vincent-Hilgard method [10]. For each test subject the entire learning process (number of trials required to achieve the learning criterion) was taken as 100% and was divided into five equal periods—20, 40, 60, 80 and 100. In addition, we analyzed the incorrect actions within each learning period. We calculated the relative error frequency of the 1st and 2nd groups as a function of the total number of responses, taken equal to 1. The data are presented in Fig. 2. From the first period we selected the initial learning instant during which the test subjects for the first time found all the programmed crossovers (zero point). Given on the curves are the errors of the 1st and 2nd groups made by the test subjects during the learning process (average values from 9 test subjects).

As is evident from Fig. 2, in the very first learning period (the zero point) /91
the error frequency in both groups was approximately the same, namely, 0.27 and 0.25. Then the errors incident to a lack of knowledge of the relations between actions and signals (1st group) dropped appreciably behind the first half of learning. The relative error frequency at the end of the second period decreased from 0.27 to 0.09. The errors connected with ignorance of the specific transitions between actions (2nd group) decreased during the same period to a considerable degree, i.e., from 0.25 to 0.19. The principal decrease of errors in the 2nd group was observed only at the end of the fourth learning period. The relative frequency of these errors in the third period was 0.16 and in the fourth 0.09.

These data permit us to conclude that in organizing a system of actions under random signal conditions the test subjects first and foremost divided their actions into two groups and related each of the groups to a specific signal. Then they established transitions between definite actions.

The next question on our research agenda touched on the method of finding rules which could be used to form a system of actions. In the program we used in teaching the test subjects all transitions were encountered with equal frequency and were governed by rules set up for any possible combination of signals. Since the people were able to learn the given program, it could be assumed that they somehow acquired these rules. It is not out of the question that the test subjects set up rules similar to the ones we used. If this is the case, then probably the transitions from key to key, carried out with the same signal combinations, were acquired by the people as some sort of a whole, i.e., as a rule. Then the difference in speed of evaluation between these transitions should be less than the difference between one of these transitions and any other one connected with a different signal combination. In order to throw light on this aspect, we determined the speed with which the test subjects learned to execute all the programmed transitions without making an error. The learning speed was expressed as the number of applications of each transition required for completion of the transition five times without an error (number of trials). The overall data obtained with the 9 test subjects are given in Table 1.

From the table it is evident that when the same signal was repeated the people learned the correct actions faster than when the signals were changed. Since the transitions incident to various signal combinations differed from each other, the difference in speed of evolution of the individual transitions was checked by making the following comparsions: 1) transitions upon "G-G" signal combinations, i.e., transitions between the 2nd and 4th keys; 2) one of these transitions with a transition attendant upon the "R-R" signal combination, i.e., transitions from the 4th to the 2nd key and from the 3rd to the 1st key; 3) transitions carried out in response to the "R-G" signal combination, i.e., transitions from the 1st to the 2nd and from the 3rd to the 4th key; 4) one of these transitions with the transition incident to the "G-R" signal combination, i.e., from the 1st to the 2nd and from the 2nd to the 1st key.

TABLE 1. Speed of Evolution of Various Transitions /93

Possible signal combinations	Transitions established by the program	Speed of evolution of transitions (number of trials)
Red - red	from 1st to 3rd key	25
	from 3rd to 1st key	27
Green - green	from 2nd to 4th key	74
	from 4th to 2nd key	62
Red - green	from 1st to 2nd key	104
	from 3rd to 4th key	108
Green - red	from 2nd to 1st key	199
	from 4th to 3rd key	124

The reliability of the differences was tested by the t criterion. The differences were considered to be reliable if $P \leqslant 0.01$. The data are given in Table 2.

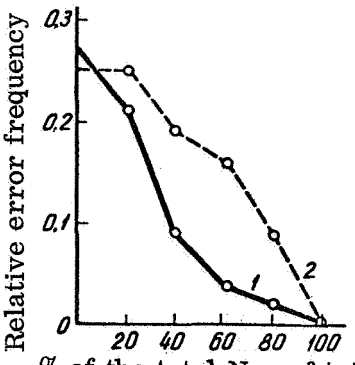

Figure 2. Relative Frequency of Errors in the Learning Process.

1—Errors of the 1st Group;
2—of the 2nd Group.

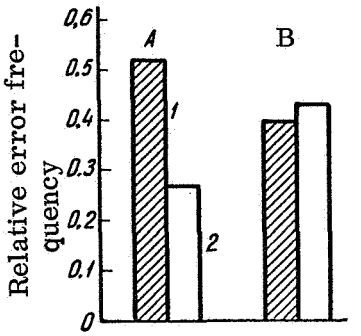

Figure 3. Relative Error Frequency When Repeating the Green (1) and Red (2) Signals.

A and B are the Groups of Test Subjects.

TABLE 2. Differences in Speed of Evolution of Transitions /94

Cases compared	Diff. in speed of evolution (no. of trials)	Reliability level	Cases compared	Diff. in speed of evolution (no. trials)	Reliability level
1	12	$0,2 > P > 0,1$	3	76	$0,3 > P > 0,2$
2	35	$0,1 > P > 0,001$	4	95	$0,01 > P > 0,00$

From the table it can be seen that only the differences between transitions relating to different signal combinations were reliable. This means that the people combined transitions in accordance with their common characteristic, a combination of signals, and set up their operational rules for each combination.

Examining the speed of evolution of the individual transitions, we took notice of the fact that on the first repetition of the red signal, seven of the 9 test subjects chose the correct key, while on the first repetition of the green signal, on the contrary, only 2 test subjects did not make a mistake. When we followed the sequence of signal from the very start of our program, it turned out that the red signal was repeated for the first time after the green signal had already been repeated ten times:

R GGGG R GGG R GGG R GGG R GG RR GG R GG RR
GG R GGGG RG R GGGR G R, etc.

Then we compared the number of incorrect responses in the first 10 repetitions of the green and in the first 10 repetitions of the red signals. These data are presented in Fig. 3, A (average data from 9 test subjects). As is evident from the figure, on repetition of the green signal incorrect answers amounted to 0.52,

whereas on repetition of the red signal they were 0.27. It is interesting that in ten repetitions of the green signal 8 of the 9 test subjects chose the correct key. On the basis of these data it can be assumed that as early as these learning periods the test subjects determined to a significant degree the relations between actions and signals and a working rule on repetition of a single signal (green). Having found this rule, they applied it to the case of repetition of the other signal, using another pair of keys. There arises the rather important question as to the capability of man to apply a ready-made rule in another, but analogous situation. In this connection we decided to change somewhat the very start of our program so that the repetitions of the red and green signals alternated, retaining the equal probability and random sequence of signals: /94

R G R G RR G R GG R G R GGGG RRR G R G RR G R GG.
RRR G R GG R G R GGG RR G R GG RRR G R G
RRRR G R, etc.

With the new program we trained 4 people who had not participated in the basic experiments. The average data obtained from these test subjects are given in Fig. 3, B. As can be seen in the figure, the fraction of errors in repeating both signals in the case of this control group of test subjects was almost the same, namely, 0.40 for the green signal and 0.43 for the red signal.

These data allow us to suppose that in finding transitions between individual actions, the test subjects combined them (the transitions) by means of a common feature, which in this case was a signal combination, and established rules for each such combination. Having set up the working rule for one concrete combination, they transferred it to another combination, but similar to the first.

CONCLUSION

In our experiments test subjects were presented with a complex problem which could be executed only by constantly requiring the test subject to perform several logic operations, such as dividing all the actions into groups related to different signals and setting up rules for transitions from one action to the next within one group and between actions associated with different groups. The aim of the investigation was to discover how people establish rules which must be known in order to solve the given problem.

Analysis of the incorrect actions taken by the test subjects during the learning process demonstrated that it was primarily the errors representative of the degree of knowledge of the relations between the actions of the human being and the external signals that decreased. Errors attendant upon ignorance of the specific transitions between actions were retained almost throughout the learning process and decreased only toward the end. The literature contains data indicating that the relationship between correct and incorrect responses at different periods of the learning process may typify the degree of difficulty of the problem to be solved. Howland [11] presents two types of learning curves. In his opinion, characteristic of easy problems in the abrupt decrease in errors at the beginning of the learning process, and at the end for harder problems. If our data are examined from this viewpoint, it can be surmised that the classification of all actions into /95

two groups related to each of the signals was an easier task for the test subjects than the finding of rules for transitions between actions. Hence it can be concluded that in forming a system of actions in the case of random signals, people organize their activity so that they first divide all the actions into groups consistent with the external signals and then attack the problem of setting up rules for transitions between actions. In doing so they must find rules for the cases of repetitions of one signal and for cases of changing signals.

When we determined the speed at which a human being established links between individual actions, we found that transitions made on the repetition of signals were evolved quicker than transitions made on the change of signals. These data permit us to assume that the finding of working rules in the case of continuous action of a single signal is easier for man than when signals changed.

According to the data of our laboratory [8], in working up programs containing a constant order and a constant number of motor acts, people used the mechanisms of grouping elements (individual actions having some sort of common feature are combined into groups which appear as a unified whole) and the mechanisms of successive acquistion of these blocks of actions. It can be assumed that when people perform actions in response to a random sequence of signals, they have also grouped these actions. In our experiments, the features linking actions may have been signal combinations, in response to which actions were executed. An examination of the difference in speed of evolution between transitions relating to different signal combinations permitted us to make this assumption. Then, in case actions performed upon repetition of a single signal are grouped together, an independent system of actions, incident only to multiple repetition of this signal, may be formed. The same is true when a second signal is repeated. Since the signals were transmitted in random sequence, the number of signal repetitions, and therefore the number of actions within each such system, changed continuously. A changein signal terminated the application of one system and transferred the activity of the test subject to the next system. In order to prevent making errors, the test subject would have had to learn, in this case, to change over from any point of this system to any point of the other. But to do this it was not enough to evaluate the present signal and to decide whether the same action was continuing or was changing. In order to establish such transitions, the test subject would have had chiefly to keep in mind the position of his preceding action. According to our data, the establishment of transitions incident to evaluation of a prior action and to allowance for the present signal presented the test /96
subjects with the basic difficulty of organizing a system of actions.

Despite the fact that the classical concept of a dynamic stereotype includes as a necessary condition the existence of always the same sequence of actions in response to a constant series of signals, we thought it was possible to assume that the form of human activity we studied is not only complex, but also stereotype, because the test subject learned to execute, in a regular fashion, the same combinations of actions each time the conditions under which he had to make a decision coincided. Having acquired all the rules contained in the program, people were able to execute actions an unlimited number of times, each time making the right choice.

The fact that rules formulated for operating in response to repetition of a single signal are transferred to the case when the second signal is repeated

indicates that, on organizing their activity, people may use ready-made rules and thus apply available knowledge.

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